STATUS OF THE CORAL REEF FISHERY IN AN ATOLL COUNTRY UNDER TOURISM DEVELOPMENT: THE CASE OF CENTRAL MALDIVES

BY

SHAHAAMA A. SATTAR,[1] SERGE ANDRÉFOUËT,[2] MOHAMED AHSAN,[1]
M. SHIHAM ADAM,[1] CHARLES R. ANDERSON,[3] AND LUCY SCOTT[4]

ABSTRACT

Fishing trips made in Central Maldives in 2006-2007 provided fresh insights on the status of the Republic of Maldives coral reef fishery. Previous assessments had been made nearly two decades prior and an update on the resource status was needed. Indeed, tourist resorts have multiplied in Maldives in the past 20 years, resulting in an increased demand for local fresh fish that resorts routinely purchase directly from local fishermen. To assess the impacts of tourism demand on fishery and fish populations, fishing locations, fishing gears, catch compositions and catch lengths are reported here for atolls of the Central Maldives. Data from the 2006-2007 fishing trips are compared to data available from Malé fish markets and to historical 1989/1991 fishing campaign data to assess potential changes in fish population structures and catches. Despite different sampling strategies, comparisons of catch data do not suggest any alarming trend. Catch composition is similar, and the most frequent species captured remain of similar sizes. Yields per square kilometre of fished reefs (1.7-3.5 tonnes/km^2) remain below published thresholds for unsustainable fisheries. Nevertheless, signs of changes should be taken seriously in the perspective of increased demand from the local tourism industry and increased value of fresh and processed fish for export markets.

INTRODUCTION

The Republic of Maldives is a tuna fishing nation. The tuna fishery was and still is the most important fishery, providing the main source of dietary protein plus visible export earnings that play a major role in the Maldivian economy (Department of National Planning, 2010). The traditional reef fishery was historically less important, and carried out in the Maldives for the purpose of local consumption typically at times when tuna catches were low. However, following the tourism industry development of the past decades, the reef fishery has expanded in volume and diversity over the years. A

[1]Marine Research Centre, H. White Waves, Moonlight Higun, Malé – 20025, Maldives. shahaama.sattar@gmail.com
[2] Institut de Recherche Pour le Développement, RD Nouméa, UMR 227 COREUS, BP A5, 98800 Nouméa cedex, New-Caledonia
[3] Manta Marine Pvt Ltd., PO Box 2074, Malé, Maldives
[4] Agulhas and Somali Current Large Marine Ecosystems Project, 18 Somerset Street, 6140, Grahamstown, South Africa

separate export-oriented grouper fishery was initiated in 1994 to target South-East Asian markets in the form of both fresh/chilled and live exports (Shakeel and Ahmed 1996; Sattar and Adam 2005). Tourism and the export industry (specifically for groupers) have likely changed reef fishery activities and resource status, but the picture remains unclear due to lack of continuous assessment and monitoring. Furthermore, tourism development and resort densities are uneven from one atoll to another and some atolls are likely more affected than others, especially in Central Maldives where resorts have been present for a long time.

Historically, two comprehensive surveys of the reef fishery were undertaken in 1988/1989 and 1990/1991 (Van Der Knaap et al., 1991; Anderson et al., 1992). Anderson et al. (1992) details the catch composition based on long-line and hand-line fishing in lagoons, shallow reefs (<50 m) and deep oceanic slopes off Shaviyani, Alifu and Laamu atolls, respectively in North, Central and South Maldives. Van Der Knaap et al. (1991) reported on Male' atoll only, in Central Maldives. These previous studies focused on finfish for food consumption, and do not report on sea cucumbers, clams, lobsters, coral, turtle, baitfish, sharks or aquarium fish fisheries which have represented other important aspect of the Maldivian reef fishery, with varying intensities, throughout past decades (Anderson and Ahmed, 1993; Anderson, 1997; Ahmed et al., 1997; Saleem and Adam, 2004; MRC, 2009).

A major result of these past surveys was the estimation for the entire Maldives of a maximum potential yield of 30,000 ± 13,000 tonnes/year for commercial reef fish (Anderson et al., 1992). These estimates were based on a number of considerations: yields from different habitats (lagoon, reefs and deep oceanic slopes); distinct fishing methods; the surface areas of Maldivian atolls estimated from marine charts; statistical relationships between fishing yields and abundance-biomass data obtained from fisheries and underwater surveys from other regions such as the lagoons of New-Caledonia (Anderson et al., 1992; Kulbicki, 1988). The suite of caveats and limitations for such computations are clearly detailed in Anderson et al. (1992). This study remains the only national-scale quantitative detailed source of information for Maldives reef fisheries to date. Maldives was also included as part of a reef fishery global meta-analysis (Newton et al., 2007), but the source of information (FAO FISHSTAT database including mostly tuna statistics for Maldives), the lack of consideration given to geographical (intra-nation, inter-atoll, inter-habitat) differences, and general selected thresholds for sustainability did not allow to draw at the national level a relevant picture of Maldives reef fishery. Maldives was nevertheless categorized with an overall low risk of overexploitation by Newton et al. (2007), which is in agreement with the final conclusions drawn by Anderson et al. (1992), who used different criteria and highlighted some caveats depending on targeted species, atolls and habitats.

In addition to the lack of recent reliable fishery data to report on resource status, a number of known factors, listed below, but of unknown consequences, called for new assessments to be conducted:

- Resort construction and increase of tourist accommodation is encouraged at the national level. The tourism industry of Maldives attracted close to 1 million tourists in 2010 (Ministry of Tourism, Arts and Culture, 2011). Similar projections and higher have been made for the future.

- A greater number of Maldivians as well as the 70,000+ expatriates working in the Maldives (Ministry of Higher Education, Employment and Social Security, website accessed April 2008) are growing to appreciate the value of reef fish to complement the usual tuna diet.
- In 2005, a study on the Maldives grouper fishery showed declines in catches and increases in smaller sized individuals (Sattar and Adam, 2005) suggesting that a fresh assessment of the entire Maldivian reef fishery was needed.
- Field observations suggest that exploitation of reef fish was carried out by fisherman in a similar manner to that of tuna (in terms of fishing without any limits), the latter of which has proven to be sustainable for decades even under long-term intense exploitation. However tuna and reef fish have comparably different life traits, fecundities and reproductive biology, growth rates, and population renewal time.
- Development of the fishery for large yellowfin tuna, which is seasonal, has led to exporters turning to reef fish during low season for tuna.
- The reef fishery provides an easier source of income in comparison to tuna fishing where fishermen have to travel long distances and spend hours, at times days away from their home and families. Reef fishing usually requires less effort (number of hours) and can be carried out close to the islands.
- Although reef fishing was carried out on a small-scale, it still played an important role in the livelihoods of island communities; many people fish reefs on an opportunistic basis whereas others carry out reef fishing as part-time employment.
- Many species of reef fish form spawning aggregations and it is evident that fishermen specifically target these aggregations, potentially removing a large part of the breeding population and at sustained exploitation levels may threaten the species (Tamelander et al. 2008).
- Finally, the effect of climate change on reef resources is unknown in Maldives. The country has previously suffered from significant coral bleaching, especially in 1998, with subsequent devastating damage to coral communities. This may have both, induced loss of habitat in the shallow reefs, and potentially impacted fish communities (Edwards et al., 2001, McClanahan et al. 2000; Loch et al. 2002; Loch et al. 2004; Bellwood et al. 2006).

Given all the aforementioned considerations, and to enable future informed and sustainable management of reef resources, it was necessary to draw an updated image of the fishery, including: its extent, the catch (quantity and composition), the gear and methodology used as well as the fate of the catch (i.e. whether it is sold to resorts or exported). We intend here to provide this much needed updated view (focussing on finfish only) using three data sets collected from:

1) Survey trips with fishermen of Central Maldives atolls to obtain fishery-dependent data on catch composition, fishing gears and methodology;
2) Collection of reef fish purchase data from tourist resorts in Maldives; and
3) Analysis of reef fish export trends based on export data collected by Maldives Customs Services.

MATERIAL AND METHODS

Reef Fishery Catch Data

Data on fishing locations and methods, main catch species and size compositions of species (Table 1, in appendix at the end of the text) were obtained in 2006 and 2007 by participating in fishing trips (n=102) with reef fishermen. Efforts were made to join the fishing trips throughout the year, irrespective of season. Species-level identification was systematic in 2007, but in 2006 catch composition of the Carangidae and Lethrinidae families could not be detailed.

As the tourism industry plays a central role in the reef fishing industry, targeted atolls were chosen based on the number of currently functional tourist resorts present in the atoll with the highest numbers of resorts falling in the Central part of the Maldives. From these atolls (namely Alifu Alifu, Alifu Dhaalu, Baa, Kaafu and Vaavu Atolls), specific islands (n=7) were chosen based on phone surveys to the Atoll Offices which identified islands where reef fishing was a regular activity and a primary source of income.

Length-frequency data for different reef fish species caught during both targeted reef fishery and as bycatch in other fisheries was also obtained from the Malé fish market during repeated visits (n=15) in 2007. Catch sold at the Malé fish market are mostly from North and South Malé Atoll.

To estimate the 2006-2007 total catch of reef fish on an annual basis and on an atoll basis, the catch data from the three atolls with the most extensive data (Alifu, Baa and Vaavu) was extrapolated by considering the surface area of lagoons and reefs for each atoll (respectively 2267, 1194 and 1058 km^2, Andréfouët et al., 2009) and fishing capacities observed during the fishing trips. Table 2 shows the number of fishing vessels in these 3 atolls as reported by the atoll offices and an estimation of the total number of fishing trips made by these vessels per month considering 21 days per month (i.e. after accounting for Fridays, public holidays and days with bad weather).

Table 2: Number of fishing vessels per atoll and island, and estimates of number of trips made by these vessels on a monthly basis.

Atoll: Baa	No. of vessels	**Atoll: Alifu Alifu / Alifu Dhaalu**	No. of vessels	**Atoll: Vaavu**	No. of vessels
Kudarikilu	4	Rasdhoo	2	Fulidhoo	2
Dharavandhoo	1	Ukulhas	4	Felidhoo	4
Dhonfanu	3	Bodufulhudhoo	9	Keyodhoo	4
Kihaadhoo	2	Mahibadhoo	3		
Thulhaadhoo	3	Mandhoo	1		
Eydhafushi	4	Kunburudhoo	3		
		Dhigurah	2		
		Dhihdhoo	1		
Total	17		25		10
Estimated no. of fishing trips/month	357		525		210

The average weight of catch per fishing trip per atoll was then used to infer the total annual catch from each atoll, for Baa, Alifu Dhaalu and Vaavu Atolls.

Reef Fish Purchase and Consumption by Tourist Resorts

The main consumers of reef fish are tourists. To estimate the total catch and consumption rates normalized by occupancy rates and total number of beds on an annual basis, tourist resorts were surveyed in 2006 and 2007 via a questionnaire which was sent to all resorts through the tourism ministry. Approximately 20% of operational resorts responded to the questionnaire and provided their reef fish purchase records, while only one resort provided details of their occupancy rates. We initially requested reef fish purchase quantities and prices on a species level and on a daily basis. However, most resorts pay a set price per kilo of reef fish regardless of the species composition. As a result, available records only show aggregate reef fish purchase. Data obtained from this survey were used to estimate average prices and revenues for fishers as well as normalized consumption rates. Results from this survey were generalized to all resorts.

Reef Fish Exports

Fisheries Statistics annually publish export values and prices of reef fish by both government and private sectors. Reef fish are exported fresh/chilled, dried or salt dried. Additionally grouper exports are reported here separately both as fresh/chilled and live.

Atoll Mapping Data

Fishing locations were overlain on atoll maps provided by the Millennium Coral Reef Mapping Project (MCRMP) to characterize the preferential areas targeted by fishermen during fishing trips (Andréfouët et al., 2006, 2009). Using high resolution satellite imagery, the MCRMP provided detailed geomorphological maps as well as consistent and accurate statistics of reef area for each Maldivian atoll (Andréfouët et al., 2009).

RESULTS

Fishing Trips Patterns and Fishing Gear

A total of 102 fishing trips were made within a period of two years (2006-2007). Islands visited and the numbers of fishing trips made from each island are listed in Table 3. The exact location of fishing sites were recorded with a GPS (Fig. 1) in order to help identify the commonly targeted sites, which could be potential spawning or feeding aggregation sites. Identification of such sites makes it easier to flag them for further management actions. In most cases fishermen did not venture away from their atolls. If they did, they remained close enough to their atolls to be able to return to their islands daily.

Table 3: Atolls and islands visited with number of fishing trips in 2006 and 2007. Kaafu Atoll comprises North and South Malé atolls.

Atoll	Island	Number of trips	
		2006	2007
Alifu Alifu	Rasdhoo	8	
Alifu Dhaalu	Mahibadhoo	11	17
Baa	Kudarikilu	13	11
Kaafu	Male'	6	3
Vaavu	Felidhoo	8	12
Vaavu	Fulidhoo	5	7
Dhaalu	Meedhoo		1
	Total	**51**	**51**

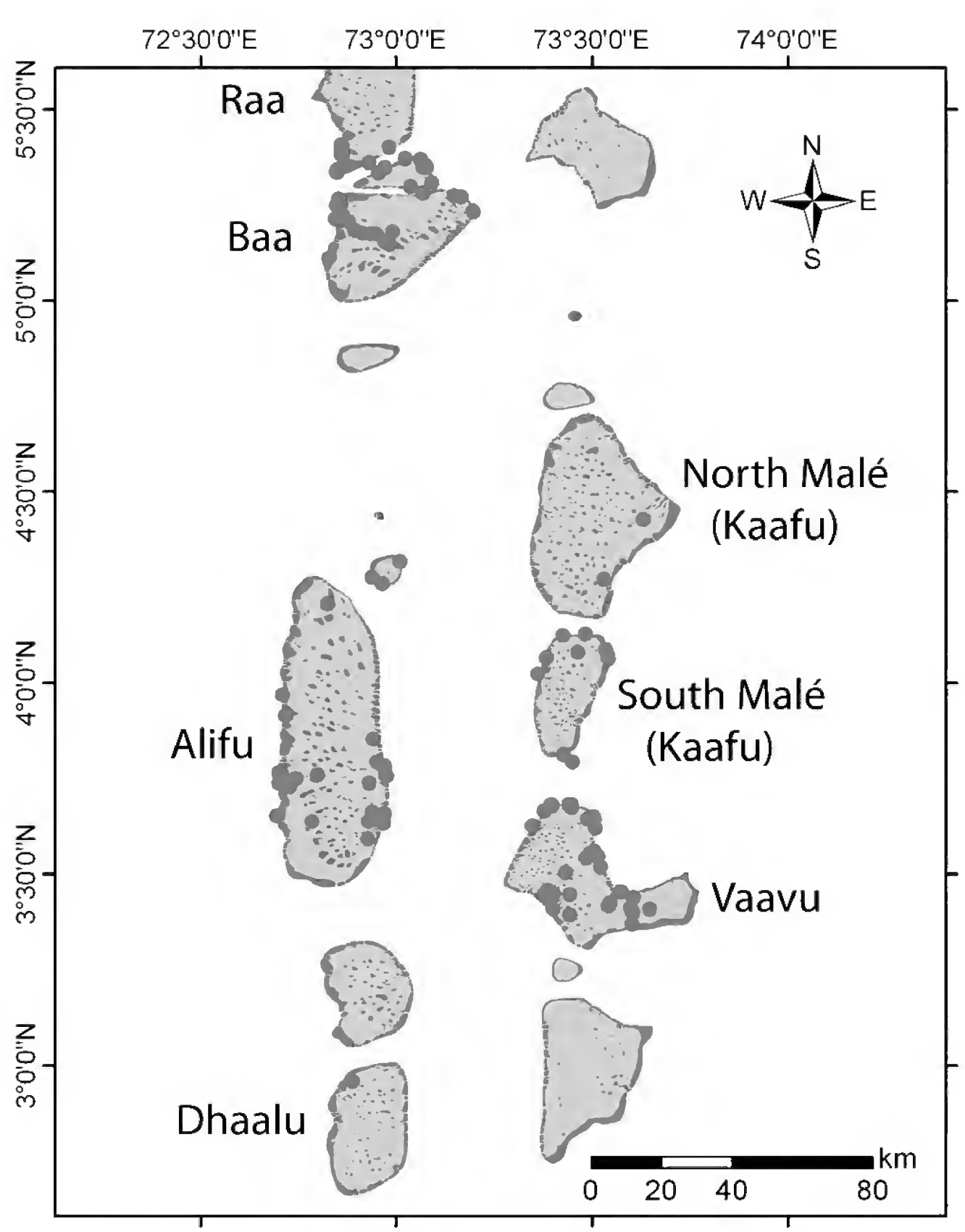


Figure 1. Map of Central Maldives and areas where fishing was carried out during the fishing trips participated in 2006-2007 (blue dots).

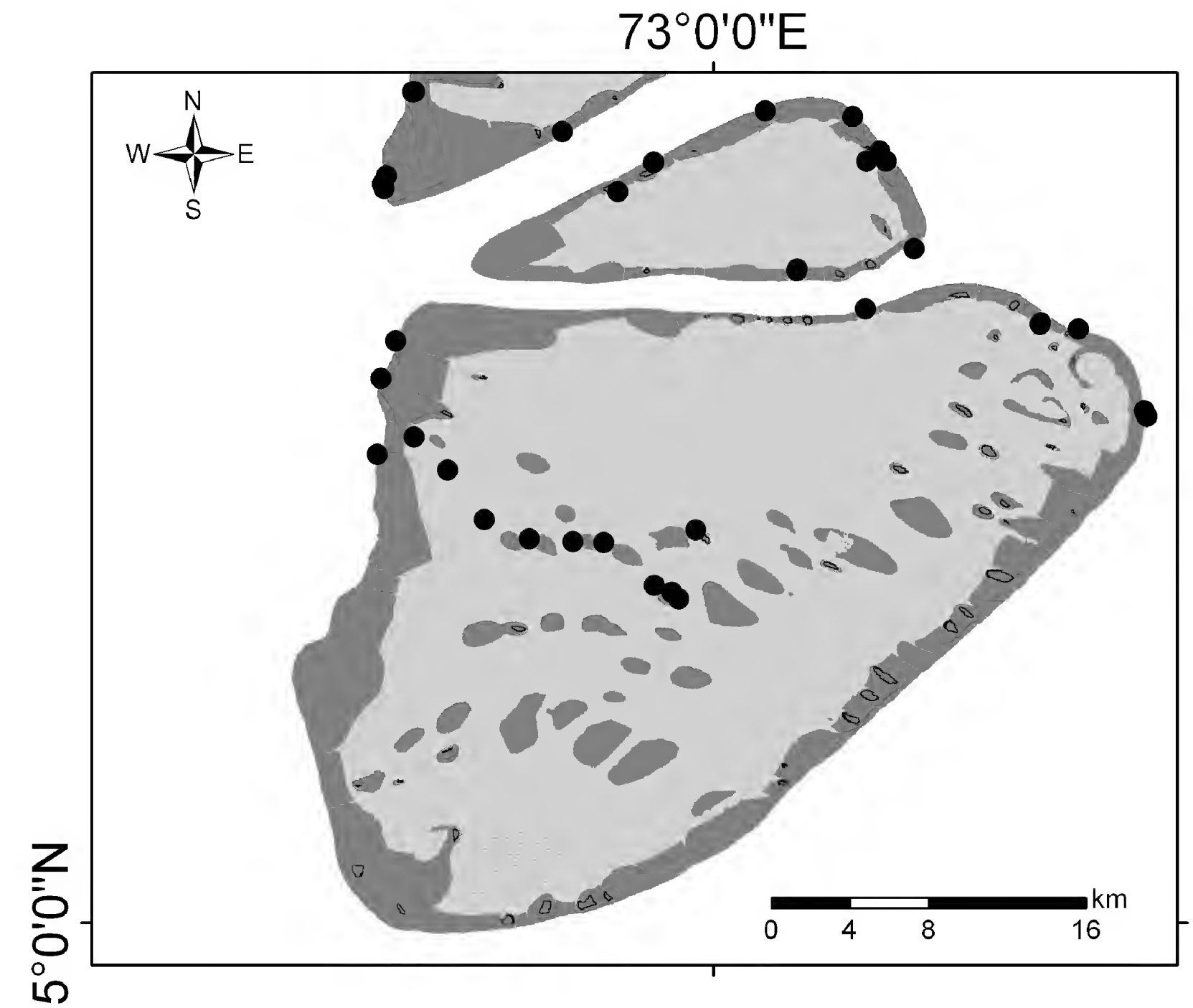


Figure 2: Location of fishing sites on Baa Atoll. Fishing sites (black dots) are located on the edges of passes (blue), oceanic deep slopes and lagoonal patch reefs (red), and at the limits of productive habitats such as coral reef flats and forereefs. Land is indicated by green colour.

Fishing locations were in most cases on forereefs on the oceanic side of atolls, in passes and at the edge of lagoonal patch reefs (Fig. 2). Small isolated submerged reefs (locally named *thila* and *haa*) were also frequently targeted (Fig. 2). With few exceptions, fishermen tended to avoid deep lagoon and deeper offshore areas.

Fishing was carried out on standard mechanized fishing boats (called *mas dhonis*) with an average of 5 crew per trip. On average, trips would last up to 12 hours, starting most commonly around 6 am. The crew would first collect bait (30 minutes up to 3 hours) then proceed to the fishing grounds (from 3 hours up to 9 hours fishing). On occasion, they would visit two to three fishing locations in one trip and return on a regular basis to particular sites. After fishing, fishermen would sell their catch to resorts or to small-scale fish processors who cook and salt/dry the fish

Fishing was carried out using a variety of gears, depending on the species being targeted: hand-lines, drop-lines, trolling and pole and line (Fig. 3).

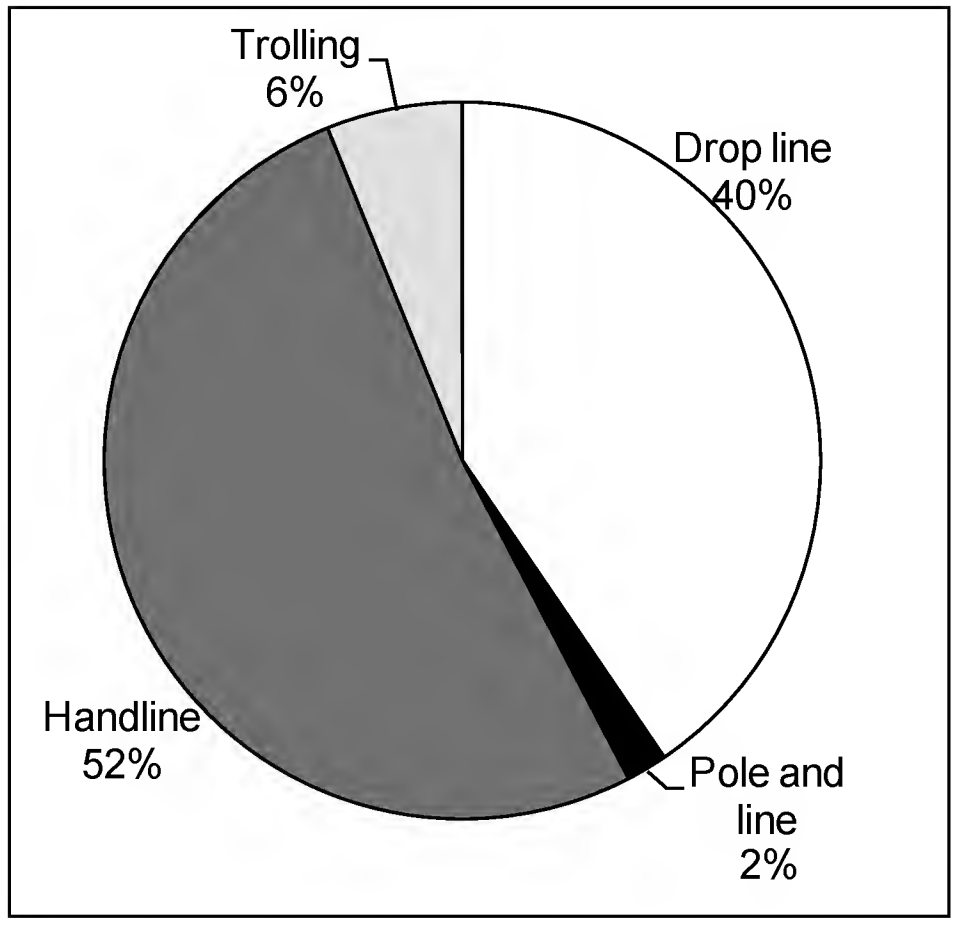


Figure 3: Proportions of gear types used by fishermen during the 2006-2007 surveys

Pole and line gear is used specifically to target tuna and is not discussed further.

- *Hand-lining:* Hand-lining was the most common method observed on all trips. Hand-lines were baited with live bait (mainly various species of fusiliers and damselfish). Since these lines do not have any weights on them they do not sink to the bottom and are used to target fish schools in the upper layers of the ocean such as trevallies.
- *Drop-lines:* Drop-lines were similar to hand-lines, but included a weight to sink them to the bottom. These lines are also baited with live bait. Another situation where drop-lines were used was when fish could be spotted by snorkelling (visually aided handlines).
- *Trolling:* On most trips, trolling was commonly employed while travelling between fishing grounds to catch large pelagic species, but not reef fish species. Targeted species included kawakawa (*Euthynnus affinis*,), wahoo (*Acanthocybium solandi*) and sailfish species (*Istiophorus platypterus*).

These preferential fishing gears were suitable for the observed fishing locations, namely at the edge of shallow reefs (Fig. 2). Multi-hook long-lines used by Anderson et al. (1992) for deep lagoon and oceanic slopes during their experimental campaigns were not used by fishermen. This implies that rigorous comparisons between the present study and Anderson et al., (1992) should be limited to the 1990-1991 hand-line data collected during the day because they targeted the same habitats. It is worth pointing out here that most destructive reef fishing gears used elsewhere in the world, such as spear guns (Cinner et al., 2009), are banned in Maldives.

In this study, fishing trips made from Felidhoo (in Vaavu Atoll) targeted groupers only. The main difference between these targeted grouper fishery trips and those targeting general reef fish was gear used, namely visually-aided handlines. For this, the fishermen

enter the water with a basket used to hold the catch. Once a grouper is spotted, a baited line (live bait) is dropped in the vicinity of the grouper. This is a very popular way of fishing (Sattar and Adam, 2005). In Vaavu atoll, catch is sold to the grouper cage (holding facility used by exporters) located within the atoll, near Keyodhoo. In Faafu Atoll, fishermen head out for a week or a month at most, and sell their catch at the end of the trip to cages in other areas, mainly Malé atoll. Grouper fishing trips always end before sunset, in contrast to all other reef fishing trips for which best fishing occurs at dusk, just after sunset.

Incomes

All reef fish fishermen sold their catch to tourist resorts within their atoll or nearby atolls, or in Malé fish markets for fishermen close enough to Malé. Selling to resorts fell into three categories:

- Vessels that are contracted by resorts and sell their catch solely to that resort. Under these contracts, vessels have to provide a certain quantity of reef fish on a monthly basis;
- Vessels that visit 3 to 4 resorts at a time, depending on demand or requests from the resort. If no requests are made, then the fishermen will visit one of the resorts at random;
- Resorts have their own staff who carry out fishing to meet the resorts requirements. These fishermen are on the payroll of the resort.

Fishermen earned an average income of approximately 1800 Maldivian Ruffiya (MRf) (or 140 US$ as in January 2011) per fishing trip. Purchase rates were on average MRf 10 (i.e. less than 1 US$) per kilo of fish in resorts, and as low as MRf 5 per kilo at small-scale processors like in Kendhoo. Some resorts in Malé Atoll paid higher rates for *Acanthocybium solandri* and *Istiophorus platypterus*. Species such as *Euthynnus affinis*, if brought to the resort in large quantities were bought at lower prices than that being paid for reef fish. Fishermen earned more by selling at the market than at resorts, as the prices there varied depending on the species and the size of the individual.

Grouper fishermen sold their catch to the nearest grouper cage or to the exporter who offered the best price. Purchase records from the grouper cage showed that they classed groupers into different price categories depending on species and weight of individuals. On average each grouper fishing trip yielded an average income of MRf 1000 (~75 US$) per trip (for an average catch of 35 groupers per trip). However, it should be noted here that the grouper trips made by the fishermen of Vaavu atoll are very different from the trips made by the fishermen of Faafu atoll, who are the leaders of this fishery. These fishermen also earn a higher income per trip than Vaavu atoll fishermen.

Catch Data

Over two years, fishing trips showed the following total composition (Fig. 4): *Carangids* (41.63%), *Lutjanids* (21.56%), *Scombrids* (13.66%), *Fistularids* and *Sphyraenids* (9.11%), *Lethrinids* (6.79%), *Serranids* (5.85%), *Coryphaenids* (0.25%) and *Xiphiids* (0.22%). Fistularids and sphyraenids were grouped together because data collection was based on local names, and both families are known as *tholhi* in Dhivehi. However, statistics of both families could be separated afterwards by looking at the length frequency plot of the collective group.

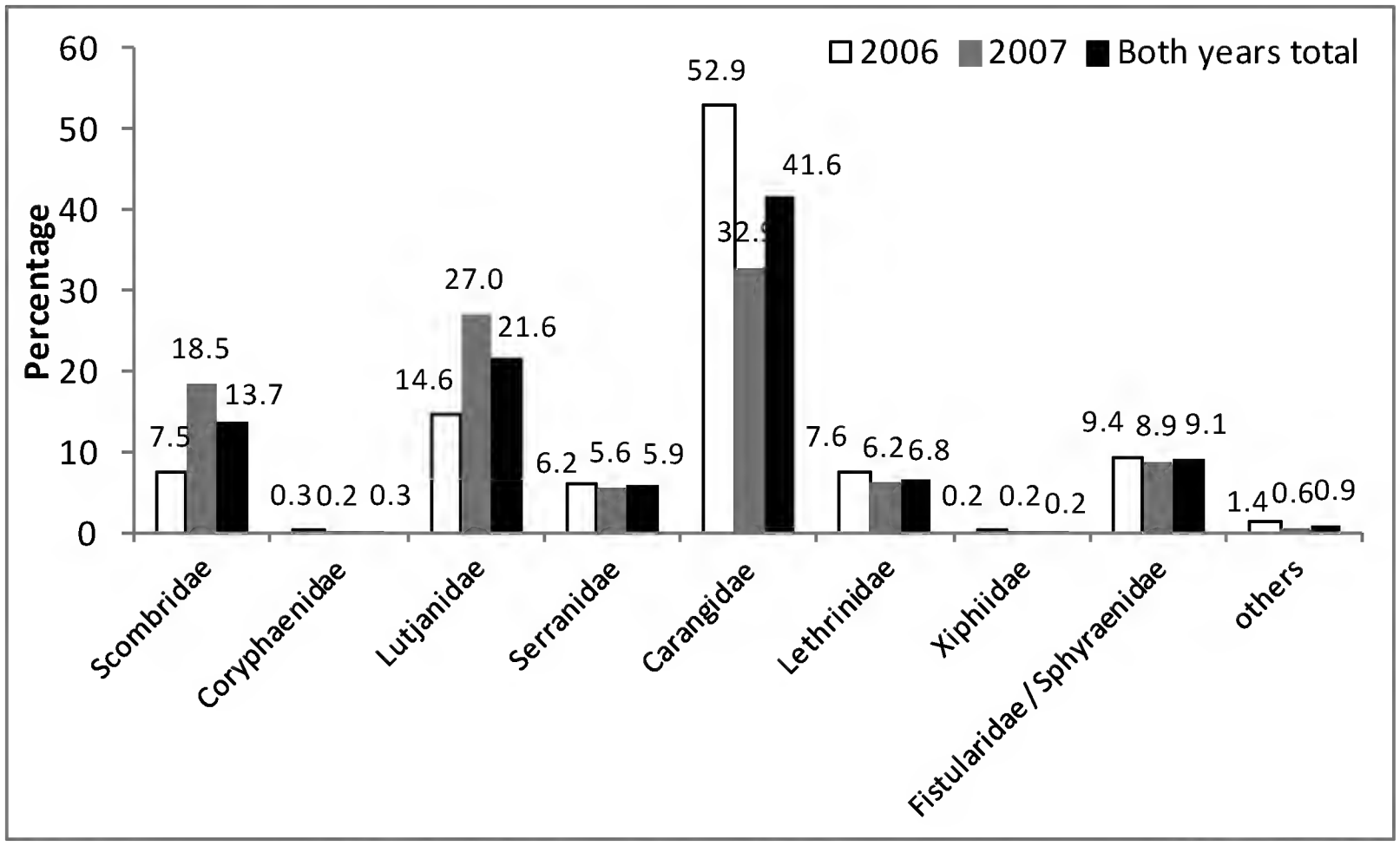


Figure 4. Percentage catch composition by numbers, of fish families caught during 2006-2007 fishing trips

In terms of number of individuals, the contribution of carangids towards the catch in 2006 and 2007 was high, but with significant annual variation. Carangids contributed more than 50% towards the catch composition in 2006, whereas in 2007 they contributed only approximately 30% towards the total. Among the carangids, the rainbow runner *Elagatis bipinnulata* contributed approximately 40% towards total catch in 2006. However, in 2007 the contribution of *E. bipinnulata* was considerably lower (approximately 15%) and the catch that year was dominated by jacks and *Aprion virescens* (with 18% and 15% respectively). Apart from Carangids, Scombrids and Lutjanids were also seen to contribute more towards the total catch in 2007 in comparison to 2006.

An island-based breakdown of total catch quantities in number of individuals over the 2 year survey period is shown in Figure 5 for Malé, Mahibadhoo, Fulidhoo, Felidhoo and Kudarikilu. Carangids form the larger group in the catch of all islands except for Felidhoo where catch is dominated by serranids due to the established grouper fishery. In 2006, all operational vessels in the island targeted grouper.

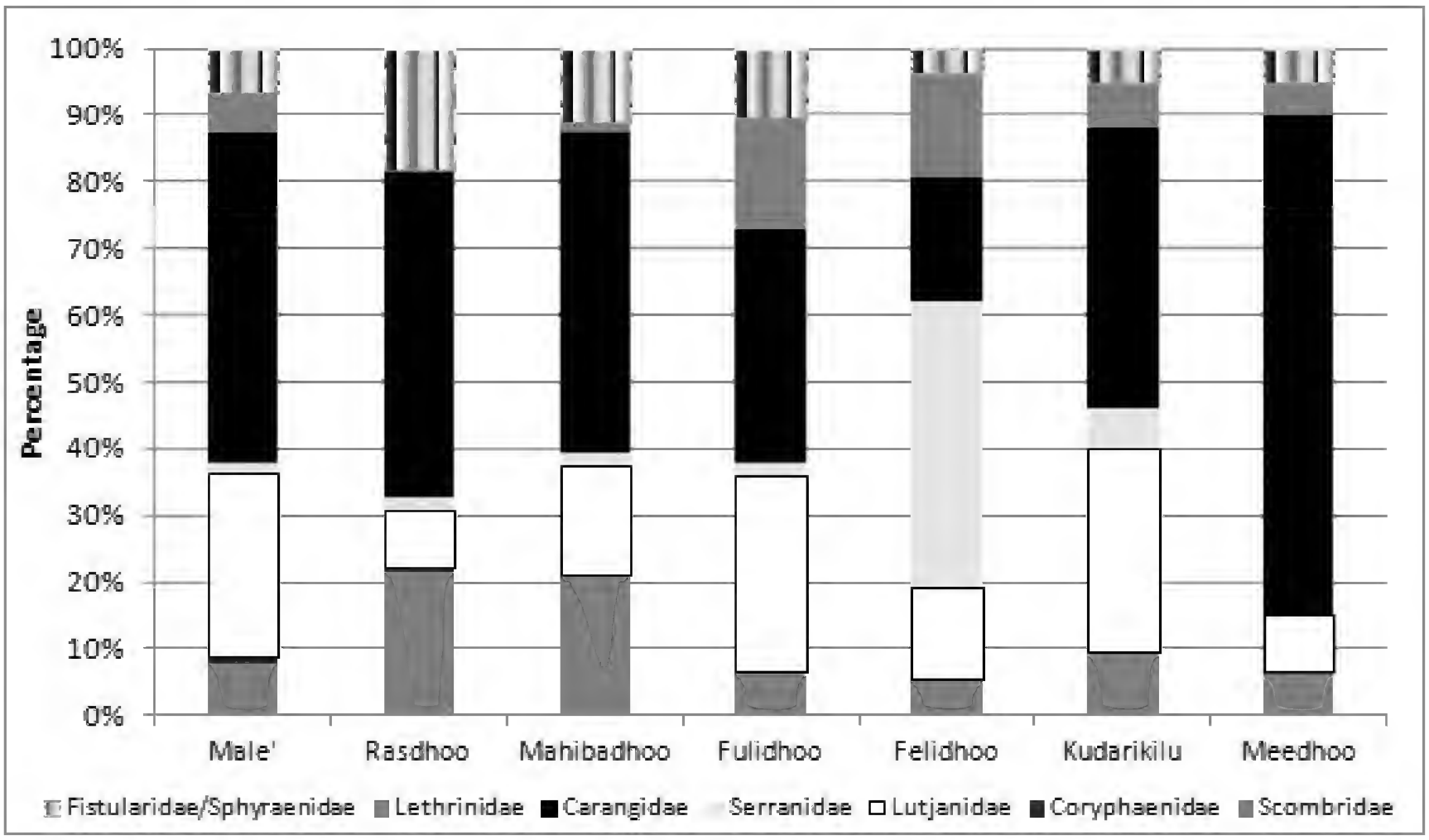


Figure 5. Island-based breakdown of catch numbers by main fish families.

Figure 6 shows the average weight and length for five of the main species for which length were recorded during fishing trips; *Lutjanus gibbus*, *Elagatis bipinnulata*, *Euthynnus affinis*, *Aprion virescens* and *Lutjanus bohar*. Length frequency distributions for these species are shown in Sattar (2008). Figure 7 provides here length frequency distributions for the main family groups.

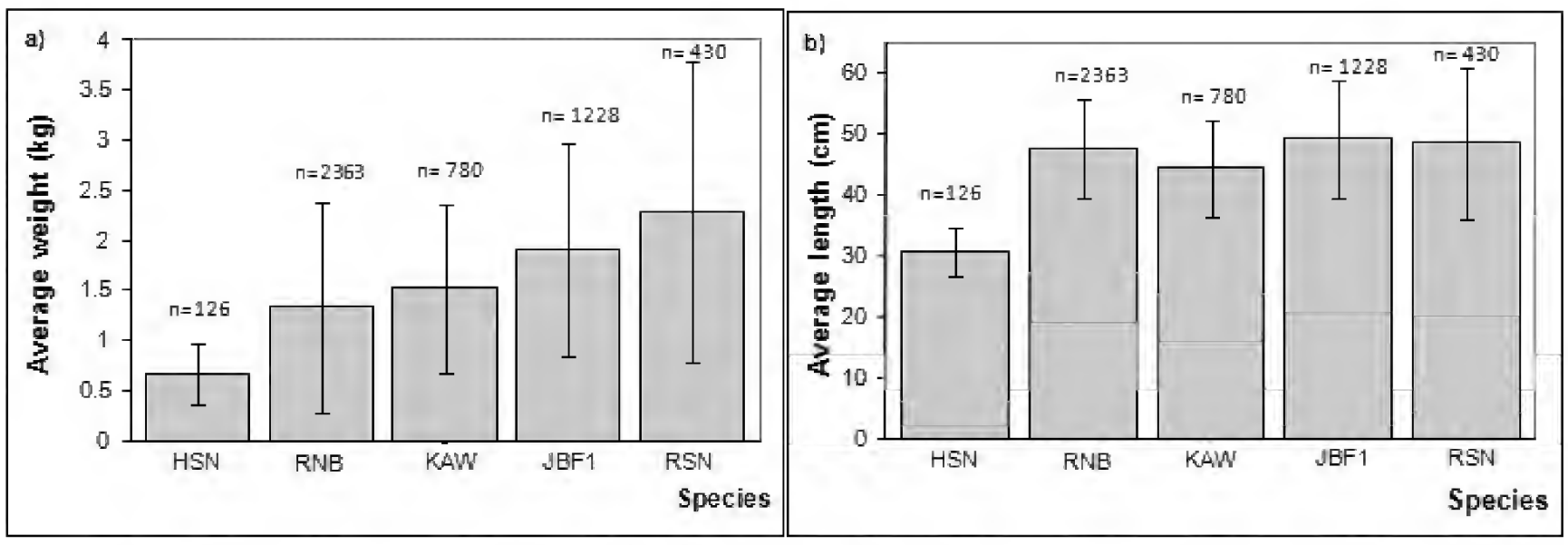


Figure 6. Average weight (a) and length (b) of the five main species caught during the surveys (HSN – Humpback snapper, RNB – Rainbow runner, KAW – Kawakawa, JBF1 – Green Jobfish, RSN – Red snapper). Error bars are standard deviations. See Table 1 in Appendix for scientific and Dhivehi names for each code

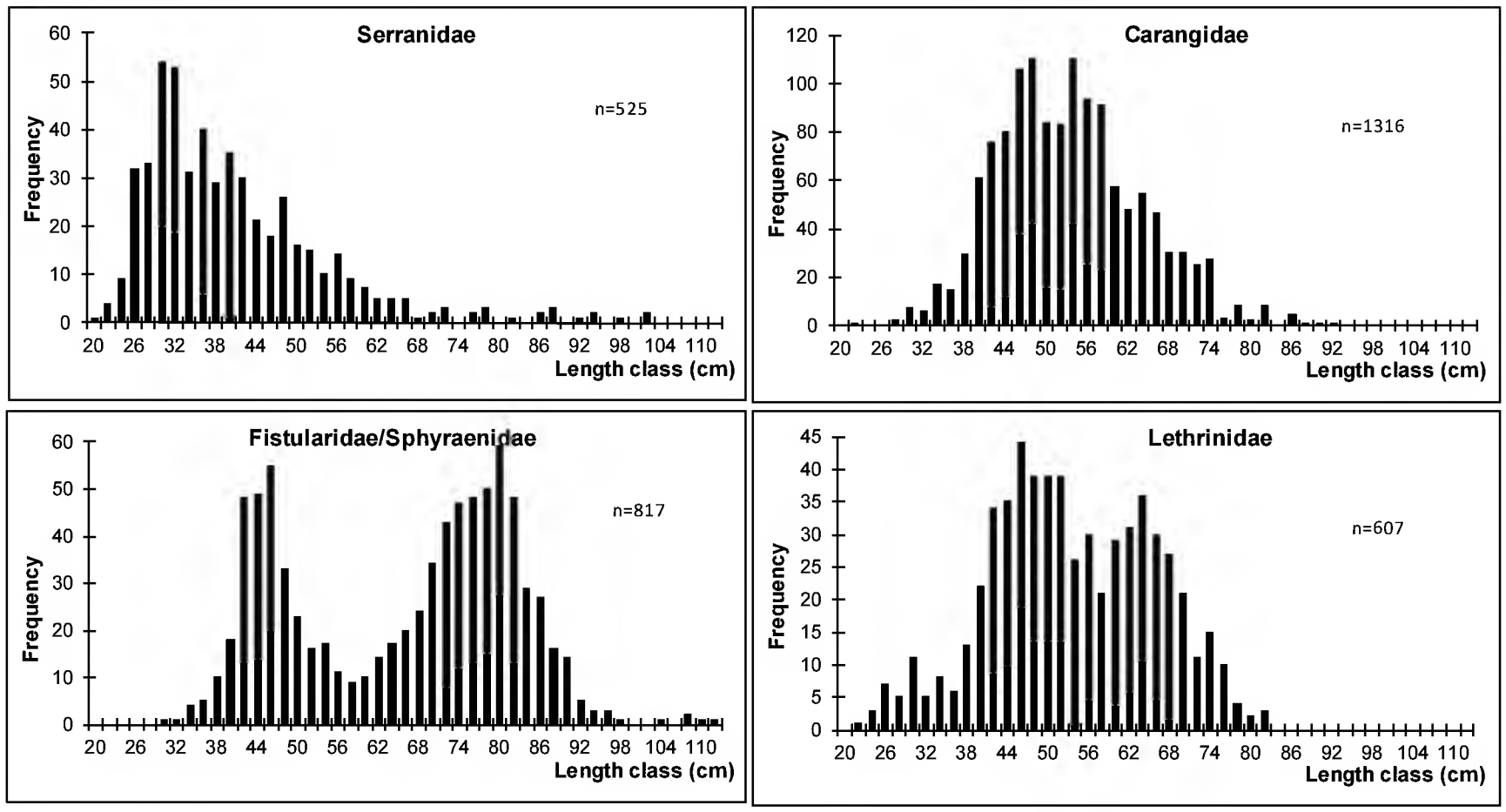


Figure 7. Size compositions of families and species assemblages caught during the 2006-2007 surveys.

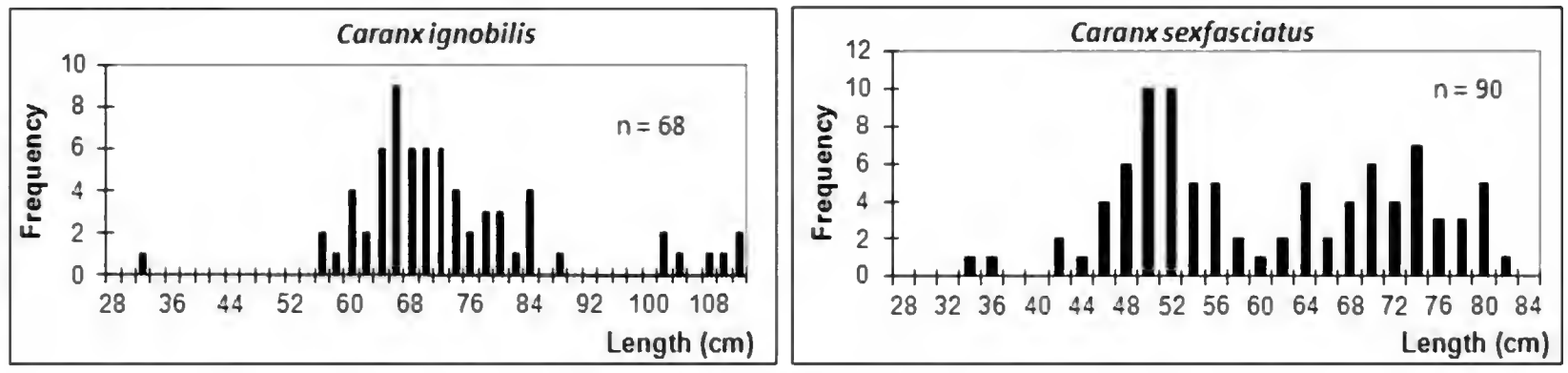
Carangids and Lethrinids display peaks at lengths between 40 and 60 cm, whereas Serranids show peak lengths in the smaller size classes, i.e. between 25 and 40 cm. 88% of the groupers were identified at a species/genus level, with 65% of these individuals belonging to the *Epinephelus*, *Plectropomus* and *Variola* genera.

Fishermen made an average of 525, 357 and 210 fishing trips per month for Alifu, Baa and Vaavu respectively. Using the average weight of catch per fishing trip for each atoll and the total area of each atoll, we inferred the total annual catch at 1452, 780, and 408 tonnes of fish for Alifu, Baa and Vaavu respectively, or in other words a yearly catch rate of 0.64, 0.65 and 0.38 tonnes per km^2 of reef-lagoon respectively.

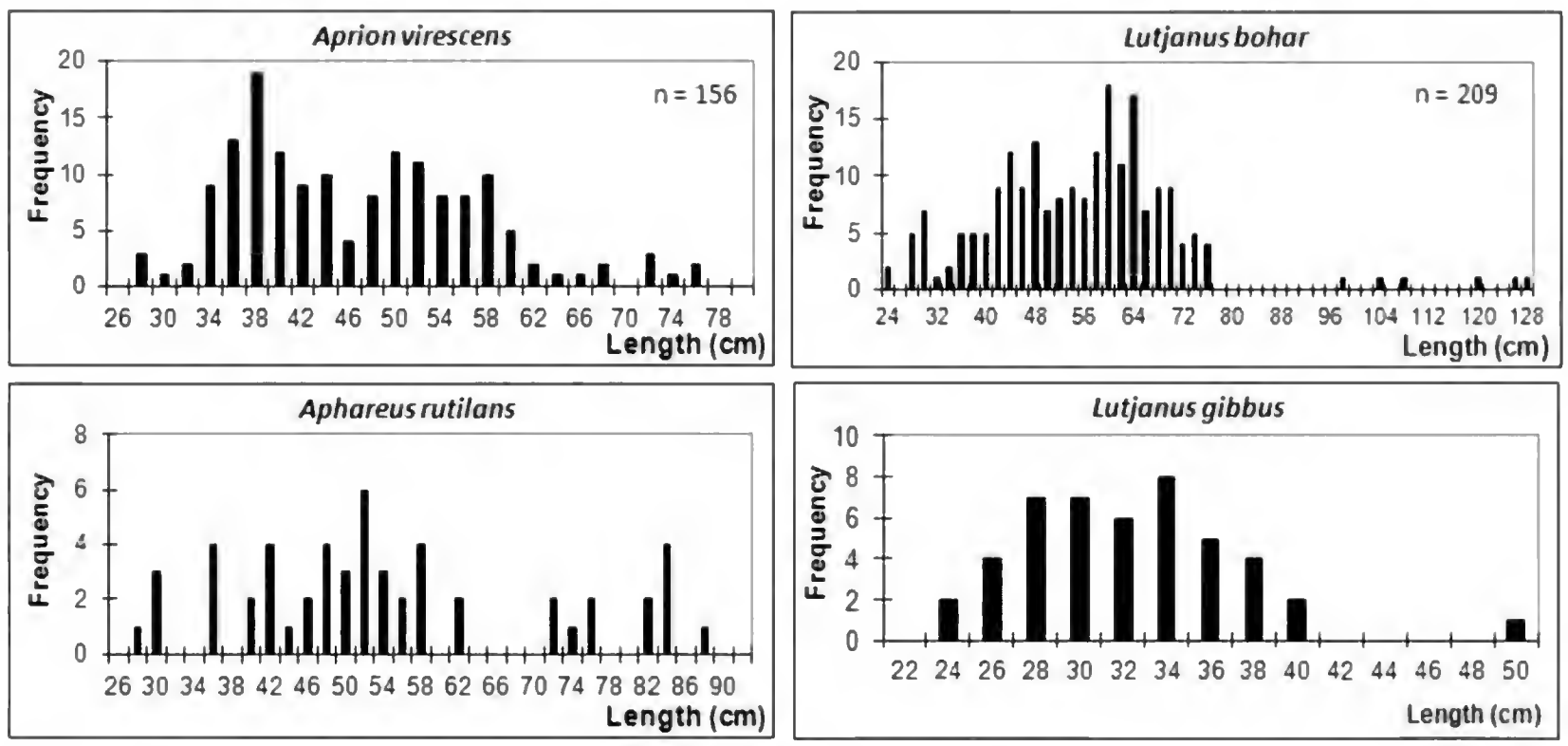
Malé Market Length Frequency Data

The most commonly represented families were Carangids, Lethrinids, Lutjanids, Coryphaenids, Sphyraenids and Serranids. Lengths were recorded for each species. Figure 8 reports length frequency for the most common species found at the market in 2007.

Family: Carangidae

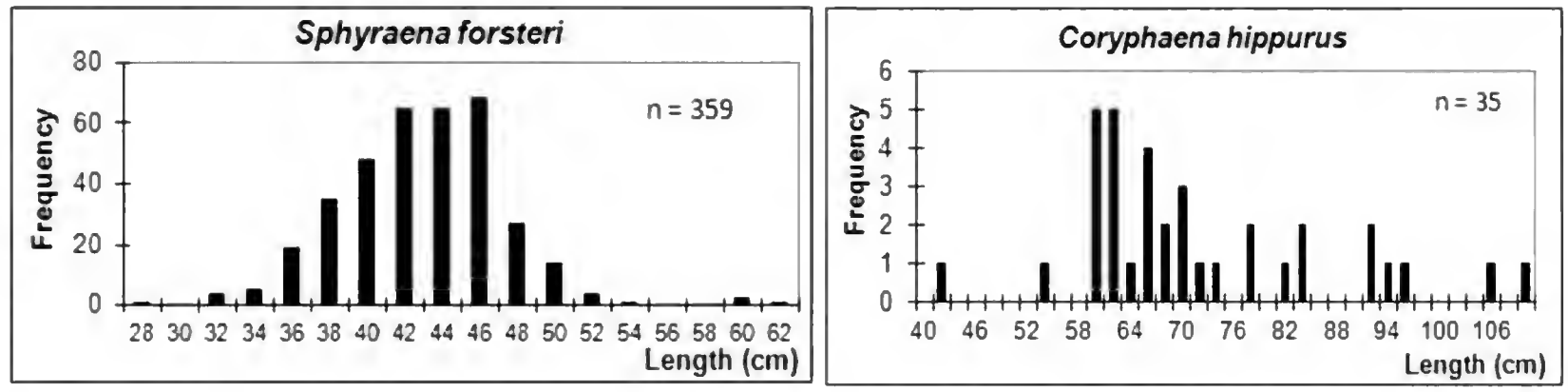


Family: Lutjanidae



Family: Sphyraenidae

Family: Coryphaenidae



Family: Lethrinidae

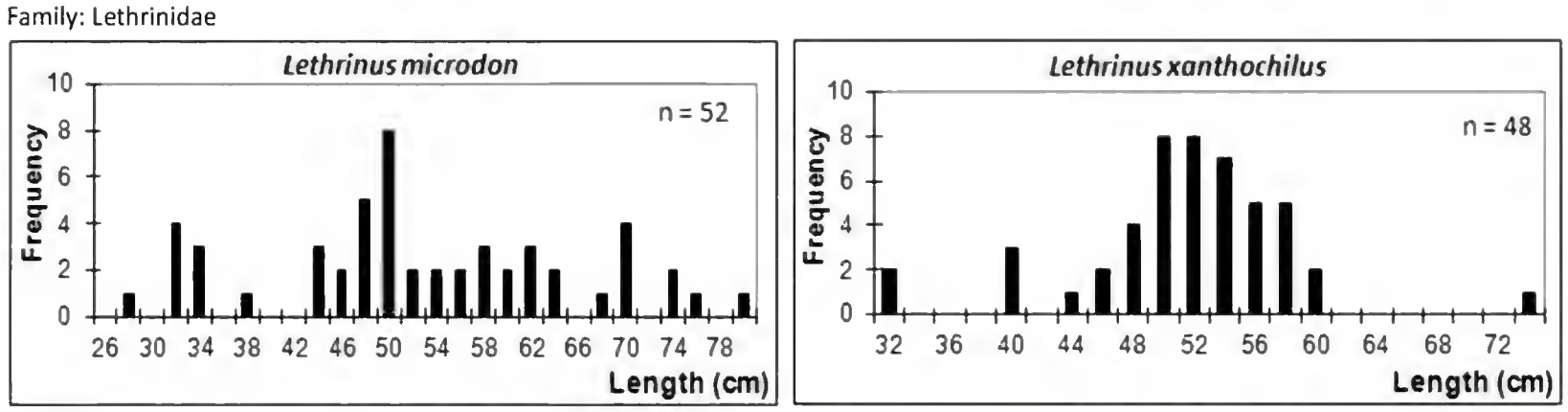


Figure 8: Length frequencies of the most commonly observed species in the Malé market, presented by families

Reef Fish Purchase and Consumption by Tourist Resorts

Only approximately 20% of the 90 Maldivian resorts contacted replied to our survey questionnaire on reef fish purchase records, while resort occupancy rates were received from only one resort. Extrapolation based on one resort's reef fish purchase for the whole year of 2006, its occupancy rate for 2006 and its number of beds, indicates that for each tourist night, an average of 1.29 kg of fish (whole fish, not cleaned or filleted) was purchased by the resort. The total number of registered beds in all resorts and hotels in Maldives for the year 2006 was 18,407 (MoTCA, 2007) and the average occupancy rate was 81.8% (MoTCA, 2007). Therefore for a total 5,495,778 tourist nights, the quantity of reef fish purchased by all resorts in 2006 would have been approximately 7100 metric tonnes. This is more than 3 times the amount (i.e. 2064 tonnes) purchased by all resorts in 1988 (Anderson et al., 1992).

Export of Reef Fish

Reef fish exports were dominated by the private sector, especially in the case of live exports, primarily of groupers to vessels visiting the holding cages. Official statistics showed that the private sector exported 99% of the volume of all reef fish exports. Trends in the export quantities for the last 12 years showed that exports of processed fish (fresh/chilled and salt/dried forms) declined abruptly in 1998 and since have stabilised around this lower range (50% less than prior to 1998). The live trade dominated by the export of species such as *Epinephelus fuscoguttatus, Plectropomus areolatus, P. pessuliferus* and *P. laevis* has been registering a steady decline (with the exception of a peak in 2001) since 1995 who dominate these exports.

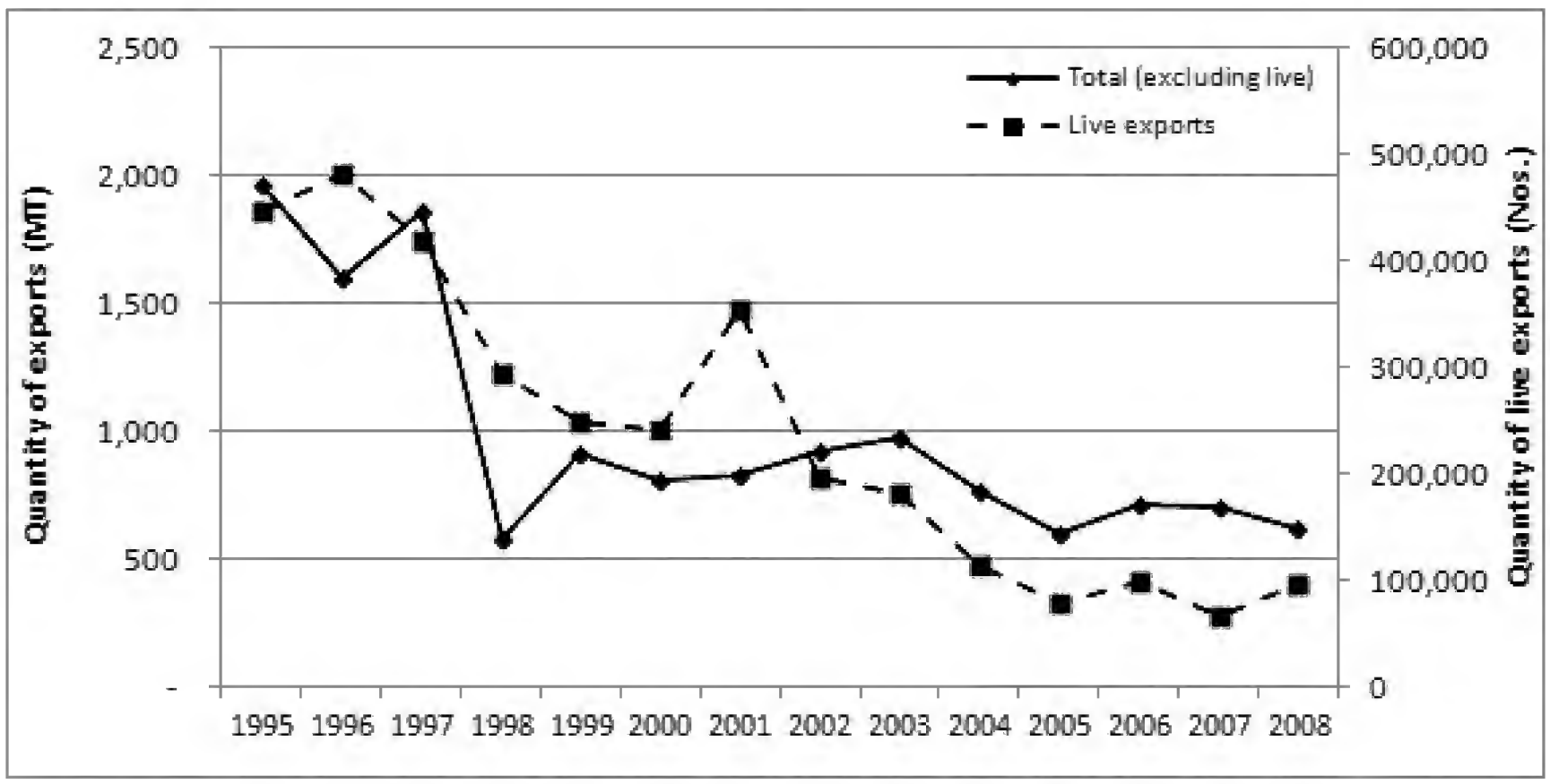


Figure 9. Total export quantity (MT) of processed fish (excluding live exports) (solid line) and Total export quantities of live reef fish in numbers (dotted line) for the last 14 years. Source: MoFAMR Basic Fisheries Statistics (1995-2008).

DISCUSSION

The 2006-2007 surveys provided a wealth of fresh data on the Maldivian reef fishery. The sampling targeted a variety of sources including fishermen during fishing trips, the current main consumers (resorts) and official export statistics. These different sources of information allowed us to draw an updated picture of reef fisheries, and to compare our findings with previous surveys from the early nineties (Van Der Knaap et al., 1991; Anderson et al., 1992). However it is important to note that, the studied atolls were different (except for Alifu and Malé), and that only a fraction of the fishery catch data (from day hand-lining and drop-lining data) can be rigorously used for comparison. In the future we hope that the data presented here can also be used for comparison with other regions of the world where reef fisheries, access to fish protein by the local population and therefore food security are at risk (Bell et al. 2009). Further, we also hope to expand the number of resorts that will provide their statistics on occupancy rates and fish purchase. One weakness of the present study lies in the extrapolations based on only one single resort.

The yield from Vaavu atoll (0.38 tonnes per km^2) is half of that from Baa and Alifu Dhaalu atolls, (0.064 and 0.65 tonnes per km^2 respectively) highlighting that generalizing results from one atoll to the next need to be made cautiously, due to either naturally different stocks or different fishing pressure. Anderson et al. (1992) call for similar prudence in their multi-atoll study. Reef fishing pressure is lower in Vaavu atoll in comparison to Baa and Alifu atoll due to the smaller market (i.e. two resorts at time of survey) in comparison to the available market in Baa and Alifu Dhaalu atoll (6 and 16 resorts respectively).

The 0.64, 0.65 and 0.38 yield values are $1/5^{th}$ to $1/15^{th}$ lower than published average yield per km^2 of coral reefs, which generally range between 1 and 10 tons per km^2 worldwide (Dalzell et al., 1996; Newton et al., 2007; Bell et al., 2009). However, since reef fishing locations were quite specific and situated around reef edges and passes (Fig. 2), the catch rate per km^2 is *de facto* largely underestimated when including lagoon areas that were not fished here. Considering only the surface of productive fished reef flats, slopes and passes (428, 299 and 234 km^2 for Alifu, Baa and Vaavu respectively), the ratio amounts to a more typical, 3.39, 2.6 and 1.74 tonnes per km^2 for Alifu Dhaalu, Baa and Vaavu respectively. This suggests that the rate of fishing based on data collected 2006/2007 is close to the limit of sustainability, if we used the published guidelines from other coral reef areas. However, wide lagoon areas remain fairly untouched.

Long-line fishing by Anderson et al. (1992) in lagoon areas provided substantial catches for a number of species that were targeted by the fishermen during our reef survey trips (cf. table 8 in Anderson et al., 1992), including the green jobfish *Aprion virescens* and red snapper *Lutjanus bohar*. It is thus surprising that these areas were not often targeted, though they would require different fishing gear. The fact that fishermen seem to stick to an easy-to-deploy fishing gear and to shallow areas suggest that they have not yet found obvious signs of resource depletion in their usual fishing grounds, nor the necessity to change their habits. Another interpretation would be that these areas have been depleted of fish of commercial value during the period between the two studies.

However, this is unlikely given the size of the lagoons, current fishing pressure levels, life traits of several of these species (e.g. jacks are highly mobile fishes) and the yields and estimated total biomass reported by Anderson et al. (1992).

Besides changes in catch per unit effort that remain difficult to quantify here and compare between studies, other indicators of possible overexploitation would be changes in catches (size and species) between the last ~20 years, as well as the current sizes of the catches compared to overfished areas worldwide. In 1989-1991, the most frequent species caught by hand-lining was *A. virescens*. This happened in every studied atoll (Shaviyani, Alifu and Laamu) and *A. virescens* contributed 32% of the total catch, on average, in weight. It was followed by *Epinephelus polyphekadion* (6.4%), *Lethrinus microdon* (5.3%) and *Lutjanus bohar* (5%). In comparison, in the present survey, *A. virescens* contributed only 13.9% towards the total catch over the 2 year period and the dominant catch was the rainbow runner *Elagatis bipinnulata*. Comparison of average weight of current catch with data obtained in the reef resources survey carried out in 1989/1991 (see Appendices I-IV in Anderson et al. 1992) suggest a decrease in average weight for *A. virescens*, *L. bohar* and *E. affinis* (Fig. 10).

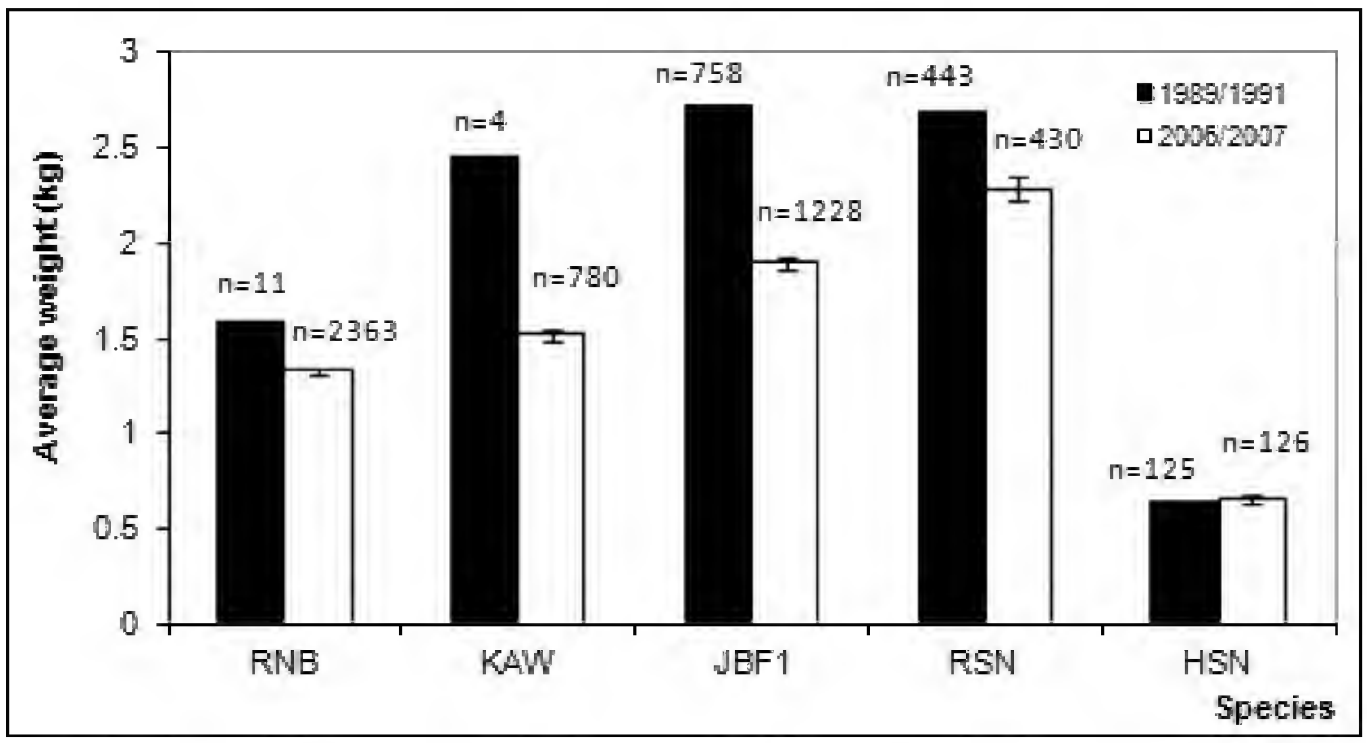


Figure 10. Comparison of average weight of main species caught in the current fishery with observations made during the 1989/1991 survey (HSN – Humpback snapper, RNB – Rainbow runner, KAW – Kawakawa, JBF1 – Green Jobfish, RSN – Red snapper). Error bars are standard error. See Table 1 in Appendix for scientific and Dhivehi names for each code. The 1989/1991 data are estimated using all fishing gear types.

Comparing our average caught fish sizes with those recorded in other areas worldwide is difficult. First, reef fishery-dependant data collected during fishing trips or in markets are scarce, not frequently updated and when they are provided in accessible literature, they may consider species that are not of interest, or absent, in Maldives fisheries. Anderson et al. (1992) noted that in Apo Island, in Philippines, only one third of the species and catches caught would be of interest for Maldivian commercial and subsistence fishery (Alcala and Luchavez, 1981). Rabbit fishes (Siganids) commonly caught and consumed in Asia and in the Pacific are completely ignored by Maldivian fishers and consumers (pers. obs., and Philippe Borsa pers. comm.). Conversely, *Lutjanus*

bohar, a prominent Maldivian catch is very often a ciguateric poisonous fish in the Pacific Ocean where it does not contribute to fishery statistics. Fishery-independent length and weight data collected by underwater visual census (UVC) are more easily accessible (e.g. Graham et al., 2005), but UVC data does not necessarily reflect fishery pressure, except when the contrast in fishing pressure is very high (Pet-Soede et al., 2001), which is unlikely to be the case presently in Maldives.

In theory, North Malé Atoll could be an interesting point for temporal and spatial comparison because i) it is historically the first atoll where significant tourism development occurred, ii) it is the most heavily populated atoll with the presence of the capital, and iii) its fish market attracts a large number of sellers (mostly from North and South Malé atolls) and buyers. Thus, it can be assumed that any signs of overexploitation would first be apparent in the Malé fish market data. However it is important to note that Malé fish market is predominantly a tuna market, and reef fish are landed opportunistically there as by-catch, and not regularly. Analysis of the data summarized in figures 6 and 8 show that *E. bipinnulata* individuals at the Malé market were generally larger (modal length at 56 cm) than those observed on the fishing trips (modal length at 46 cm). Conversely, *A. virescens*, peak length was shorter (38cm) at the Malé market. For most other species, size classes distribution commonly observed in remote atolls and those at Malé market were similar, including for *L. bohar* and *L. gibbus*. In the case of *L. bohar,* very large individuals (i.e. 100+ cm) were also reported at the Malé market. Even if these large specimens could reveal fishing during spawning seasons in shallow areas (older specimens live deeper, Anderson et al. (1992)), we conclude that there are no signs of overfishing from Malé fish market data when compared to other atolls. Moreover, similar conclusions arise when comparing with historical Malé data from Van Der Knaap et al. (1991) and Anderson et al. (1992). Anderson et al. (1992) had already noted the surprisingly good shape of the resources in Malé atoll compared to other sites, given its high fishing pressure.

However, it should be noted here that, while the species caught in the generic reef fishery which targets the tourism market, seem to be in good condition with respect to their stocks, the grouper stocks show a completely different picture. Groupers have been intensively exploited since the early 1990s, for the export market and the fishery and export industry have been showing quite a worrying trend. Grouper fishery is on a decline with decreased catch quantities comprised of high number of small sized individuals. This is especially true for the high valued species such as those belonging to Epinephelus and Plectropomus genera. More than half of serranids sampled during the fishing trips belonged to genera/species that are capable of growing to larger sizes, such as *Epinephelus*, *Plectropomus* and *Variola*. Hence the peak lengths at small size classes for groupers reveal a worrying trend, i.e. the catch of small individuals of species which could grow to much larger sizes.

Fish market data cannot be related with export data, but these also contribute significantly to the reef fishery industry. Figure 9 shows the amount of fish exported to foreign markets. Since 1996, there is a general decrease in weight for both processed (salted, dried, or fresh/chilled fish) and live fish trades. It must be noted that rainbow runners and wahoo make a significant part of the salted-dried processed exports, but not

of the chilled-fresh exports (separate data not shown). The decrease for the years 2004 and 2005 could be explained by the large number of fishermen leaving the grouper and reef fishery and turning towards yellowfin fishery at that time, possibly due to the better income from the fishery. In agreement with previous reports on live grouper exports (Sattar and Adam, 2005), the trend in total export quantities of live reef fish (groupers inclusive) is decreasing, due to the decreased availability of species and sizes required for the live market. Under-reporting is also likely and the official statistics used here may underestimate the actual level of exports. However, although export quantities of live reef fish are decreasing, buyers are paying higher prices for less available items. This in itself is an incentive for exporters and fishermen to maintain the activity in times of declining fisheries worldwide. The decline is also due to the apparent high turnover of owners of the cages used to maintain fish alive as observed between 2006 and 2007 during our surveys in Vaavu atoll.

Overall, Maldives reef fisheries seem currently at a state that does not show overexploitation of the resources, except for groupers. However, a number of caveats are worth taking into account. First, our estimated catch is likely an underestimate of the total as it does not account for the catch made by fishermen who fish on an opportunistic basis and sell their catch to the islands and villagers. It also does not account for the grouper fishermen from Baa atoll who do not get their catch solely from within the atoll, but make fishing trips throughout the Maldives, which could last for a month at the least (Sattar and Adam, 2005). Second, the reef fish market is not negligible compared to tuna and given current resort development plans is likely to continue increasing and expanding. Although lower than the value estimated by Van Der Knaap et al. (1991) (1.67 kg), the consumption rate is of the same order and suggest that future tourism development and higher number of tourists will steadily impact the reef fishery. Purchase prices of reef fish by the resorts varied between 5 to 18 MRf per kilo of reef fish, in agreement with the average purchase price observed on the fishing trips, i.e. MRf 10 per kilo of fish. This indicates that for the year 2006, an approximate total of MRf 71 million (US$5.5 million) was spent on the purchase of reef fish. Prices paid for reef fish purchases by resorts did not vary with the time of the year in comparison to what is observed in grouper cages where when fishing is low, exporters pay higher amounts than they would during periods of good fishing (Sattar and Adam, 2005). Third, the reef fish export industry is likely more wide-spread than the picture drawn through official statistics compiled for this study. Indeed, it is a common practice among yellowfin tuna exporters to turn towards reef fish during times of low yellowfin catches.

CONCLUSION

The data collected during the 2006-2007 surveys in Central Maldives atolls and Malé fish markets provided fresh insights and a new benchmark for the status of the fishery, compared to the previous assessments achieved 20 years ago, despite some constraints in comparisons due to study design differences.

Considering historical and new data, the status of the Maldivian reef fishery (apart from the grouper fishery) appears to be in good state, with opportunity to expand in the future, in contrast with many other island and atoll nations worldwide (Newton et

al., 2007, Bell et al., 2009). On the good side, we report that dominant fishing gears were single hand-lines used in shallow areas around reef edges, and not the more destructive fishing devices used elsewhere such as spear guns or dynamite fishing (Pet-Soede et al., 2001, Cinner et al., 2009) which are banned in Maldives. The yield computed for the preferentially fished area is low to medium (1.7-3.5 tonnes/km^2), and well within the limits of sustainability considered elsewhere worldwide (Newton et al., 2007). Average caught fish sizes remain good, and exports of reef fish are decreasing. Furthermore, during these surveys, fishermen seldom fished the vast deeper lagoon areas that proved to be productive during the 1990-1991 fishing trips with long-lines (Anderson et al., 1992). Finally, data from the Malé fish market, despite being located on the most populated atoll, suggest that the population structures of the main targeted species have not been negatively affected and is similar to nearby Central Maldives atolls. On the other hand, it does not mean that the situation is exactly the same as 20 years ago, nor that signs of changes should not be taken seriously in view of increased demand from the local tourism industry and increased value of fresh and processed fish in export markets. Even if not considered here, other signs of degradation exist such as the rapid and severe decline of sharks due to the shark fin fishery (Anderson and Ahmed, 1993), before this practice was officially banned in 2009. For instance, Chabanet et al. (this issue) do not report any sightings of sharks in Baa atoll in their 2009 UVC observations.

Careful planning and management of fishery resources on an atoll basis will be needed shortly to account for other factors than current fishermen practices. For this, a robust long-term fishery monitoring and management program designed by atoll with varying environmental features and varying fishing pressure as well as varying management measures such as no-take zones and protected spawning aggregations would be needed in parallel to the monitoring of the quality of reef and lagoon habitats possibly damaged after bleaching events and other disturbances. Inter-atoll variations need to be taken into account if future monitoring occurs by considering the different rates of tourism development and the latitudinal environmental and geomorphological variations found across Maldives (Anderson et al., 1992). Monitoring of reef fish catch should be planned in coordination with the resorts. This can be enforced by making recording of their reef fish purchase (including details such as species and quantity purchased, date of purchased, fishermen details, and size and weight) an obligatory criterion for obtaining their license to operate. Proactive actions by the resorts themselves should be encouraged. For instance, one resort has its own regulations and did not purchase individuals smaller than a certain size or if they were immature, or did not purchase any fish at all if sharks were found on board even if caught accidentally. Species-specific regulations should also be further promoted at first signs of stock degradation since there are no management regulations for reef food fish except for the declaration of the Napoleon wrasse (*Cheilinus undulates*) as a protected species and the export ban on all species of parrotfish. This would complement current regulations and guidelines existing for the aquarium trade fishery and the bait fishery.

ACKNOWLEDGEMENTS

Several people have contributed to this project during its various stages. Most importantly we thank all the MRC staff who took part in the field trips and would like to note their hard work in collecting all data required for this survey: Mohamed Ahusan, Ibrahim Asghar, Haanee Badeeu, Hassan Haamid, Mariyam Shafiya Hassan, Fahmeeda Islam, Aminath Lubna, Shafiya Naeem, Ahmed Najeeb, Ali Yashau and Hussein Irufan. Secondly we would like to thank all the fishermen who took us out on their trips with them. Additionally, various tourist resorts contributed towards this study, both in their data contribution as well assistance on our visits to the resort with the fishermen. Thanks are also due to the staff of ERSS of the Ministry of Fisheries, Agriculture and Marine Resources, as well as all those at MRC and other government institutes and private companies who assisted during the various stages of this study. Last but not least we would like to thank all Atoll and Island offices, and island communities who assisted us on our various survey trips.

REFERENCES

Alcala, A. C., and Luchavez T.
1981. Fish yield of the coral reef surrounding Apo Island, Negros Oriental, Central Visayas, Philippines. *Proc. 4th Int.Coral Reef Symposium*, Manila. 1:69-73.

Anderson, R. C., Z. Waheed, M. Rasheed and A. Arif
1992. Reef Fish Resources Survey in the Maldives - Phase II Reef Fish Research and Resources Survey. B.o. B. Programme. Madras, Bay of Bengal Programme/ FAO: 54 p.

Anderson, R. C., and H. Ahmed
1993. The shark fisheries in the Maldives. Malé (MOFA), Rome (FAO), p. 1-73.

Anderson, R. C.
1997. The Maldivian tuna livebait fishery – Status and trends. Workshop on Integrated Reef Resources in the Maldives BOBP/REP/76: 312 p.

Andréfouët, S., F. E. Muller-Karger, J. A. Robinson, C. J. Kranenburg, D. Torres-Pulliza, S. A. Spraggins, and B. Murch.
2006. Global assessment of modern coral reef extent and diversity for regional science and management applications: a view from space. *Proc. 10th Int. Coral Reef Symposium.* Japanese Coral Reef Society, Okinawa, Japan. pp. 1732-1745

Andréfouët, S., N. Chagnaud, and C. Kranenburg.
2009. Atlas des récifs coralliens de l'Océan Indien Ouest. Atlas of Western Indian Ocean Coral Reefs. Centre IRD de Nouméa, Nouméa, Nouvelle-Calédonie. 102 p.

Ahmed, H., Mohamed, S., Saleem, M. R.
1997. Exploitation of reef resources – Beche-de-mer, Reef sharks, Giant clams, Lobsters and others. Workshop on Integrated Reef Resources in the Maldives BOBP/REP/76: 312 p.

Bell, J., M. Kronen, A. Vunisea, W. Nash, K. G, A. Demnke, S. Pontifex, and S. Andréfouët.
2009. Planning the use of fish for food security in the Pacific. *Marine Policy* 33:64-76

Bellwood, D. R., Hoey, A. S., Ackerman, J. L., Depczynski, M.
2006. Coral bleaching, reef fish community phase shifts and the resilience of coral reefs. *Global Change Biology* 12 **(9)**: 1587 - 1594

Cinner, J. E., T. R. McClanahan, N. A. J. Graham, M. S. Pratchett, S. K. Wilson, and J. B. Raina.
2009. Gear-based fisheries management as a potential adaptive response to climate change and coral mortality. *Journal of Applied Ecology* 46:724-732

Dalzell, P., T. J. H. Adams, and N. V. C. Polunin.
1996. Coastal fisheries in the Pacific islands. *Oceanography and Marine Biology*, 34:395-531

Department of National Planning
2010. Statistical Yearbook of Maldives 2010. DNP, Male', Republic of Maldives

Edwards, A. J., S. Clark, H. Zahir, A. Rajasuriya, A. Naseer and J. Rubens
2001.Coral bleaching and mortality on artificial and natural reefs in Maldives in 1998, Sea Surface Temperature anomalies and initial recovery. *Marine Pollution Bulletin* 42: 7-15

Graham, N., N. Dulvy, S. Jennings, and N. Polunin.
2005. Size-spectra as indicators of the effects of fishing on coral reef fish assemblages. *Coral Reefs* 24:118-124

Kulbicki, M.
1988. Correlation between catch data from bottom longlines and fish censuses in the SW lagoon of New-Caledonia. *Proc. 6th Int. Coral Reef Symposium*, Townsville. pp. 305-312

Loch, K., Loch, W., Shuchmacher, H. and See, W. R.
2002. Coral recruitment and regeneration on a Maldivian reef 21 months after the coral bleaching event of 1998. PSZN I: *Mar. Ecol*. 23 **(3)**: 219 – 236

Loch, K., Loch, W., Shuchmacher, H. and See, W. R.
2004. Coral recruitment and regeneration on a Maldivian reef four years after the coral bleaching event of 1998. Part 2. PSZN I **Mar. Ecol**. 25: 145 – 154

McClanahan, T. R.
2000. Bleaching damage and recovery potential of Maldivian coral reefs. *Mar. Poll. Bull*. 40: 587-597

Ministry of Higher Education, Employment and Social Security, website accessed April 2008:
http://www.employment.gov.mv/Resources/Statistics/2008/Indicators/Expatriate%20Employment%20Annual%20Growth%20Rate,%202003%20-%202007.pdf

Ministry of Tourism, Arts and Culture
2011. Tourism Yearbook 2011. Statistics and Research Section, Ministry of Tourism, Arts and Culture, Male', Maldives.

MoTCA.
2007. "Khabaru - midhiya aharu nimunu iru Raahje ah 601,923 fathuruverin ziyaaraiy kohfai vey." 88-SR/NEWS/2007/01 Retrieved January 29, 2007.

MRC
2009. "Miyaru masverikamuge haalathu 2". Marine Research Centre, Ministry of Fisheries and Agriculture. 33p.
Newton, K., I. M. Côté, G. M. Pilling, S. Jennings and N. K. Duly
2007.Current and future sustainability of Island Coral Reef Fisheries. *Current Biology* 17:655-658
Pet-Soede, C., W. L. T. van Densen, J. S. Pet, and M. A. M. Machiels.
2001. Impact of Indonesian coral reef fisheries on fish community structure and the resultant catch composition. *Fisheries Research* 51:35-51.
Saleem, M. R. and Adam, M. S.
2004. *Review of aquarium fishery of Maldives*. Marine Research Centre, Male', Maldives. 33p.
Sattar, S. A.
2008. *Reef fishery Survey 2006-2007*. Marine Research Centre, Malé. 66 p.
Sattar, S. A., and M. S. Adam
2005. *Review of grouper fishery of the Maldives with additional notes on the Faafu Atoll fishery*. Malé (Marine Research Centre), pp. 1-64
Shakeel, H. and H. Ahmed
1996. Exploitation of Reef Resources, grouper and other food fishes in the Maldives. Workshop on Integrated Reef Resources in the Maldives BOBP/REP/76: 312 p.
Tamelander, J., Sattar, S., Campbell, S., Hoon, V., Arthur, R., Patterson, E. J. K, Satapoomin, U., Chandi, M., Rajasuriya, A., and Samoilys, M.
2009. Reef fish spawning aggregations in the Bay of Bengal: awareness and Occurrence. *Proceedings of the 11th Coral Reef Symposium*, Ft. Lauderdale, Florida
Van Der Knaap, M., Z. Waheed, H. Shareef and M. Rasheed
1991. Reef fish resources survey in the Maldives. Reef fish Research and ResourcesSurvey. B. O. B. Programme. Madras, Bay of Bengal Programme/ FAO: 60 p.

Appendix

Table 1: List of studied fish families/species, in scientific, English and local (Dhivehi) appellations. Carangidae and lethrinidae were described at species level in 2007.

Code	Scientific name	English name	Dhivehi name
	Snapper (Lutjanidae)		
JBF1*	*Aprion virescens*	Green jobfish	Giulhu
JBF2*	*Aphareus rutilans*	Rusty jobfish	Rankarumas
HSN*	*Lutjanus gibbus*	Humpback red snapper	Ginimas
RSN*	*Lutjanus bohar*	Red snapper	Raiymas
FON	*Macolor niger*	Black and white snapper	Foniyamas
FON	*Macolor macularis*	Midnight snapper	Kalhu foniyamas
	Jack (Carangidae)		
RNB	*Elagatis bipinnulata*	Rainbow runner	Maaniyamas
JCK		Jacks (species level data absent in 2006)	Handhi
JCK	*Alectis ciliaris*	African pompano	Naruva handhi
JCK	Carangoides caeruleopinnatus	Coastal trevally	Vabboa handhi
JCK	*Carangoides ferdau*	Blue trevally	Dhabaru handhi
JCK	*Carangoides gymnostethus*	Bludger trevally	Mushimas handhi
JCK	*Carangoides orthogrammus*	Island trevally	Thumba handhi
JCK	*Caranx ignobilis*	Giant trevally	Muda handhi
JCK	*Caranx lugubris*	Black trevally	Kalha handhi
JCK	*Caranx melampygus*	Bluefin trevally	Fani handhi
JCK	*Caranx sexfasciatus*	Bigeye trevally	Haluvimas
JCK	*Gnathodon speciosus*	Golden trevally	Libaas handhi
JCK	*Scomberoides lysan*	Doublespotted queenfish	Kashi vaali
JCK	*Seriola rivoliana**	Almaco jack	Andhun handhi/ Andhun mas
SBR	**Emperor (Lethrinidae)**	Seabreams (species level data absent in 2006)	Filolhu
SBR	*Gymnocranius griseus*	Grey large-eye bream	Kandu uniya
SBR	*Lethrinus conchyliatus**	Redaxil emperor	Thun raiy filolhu
SBR	*Lethrinus harak*	Thumbprint emperor	Lah filolhu
SBR	*Lethrinus microdon**	Smalltooth emperor	Thundhigu filolhu
SBR	*Lethrinus olivaceus**	Longnose emperor	Filolhu
SBR	*Lethrinus rubrioperculatus**	Spotcheek emperor	Kalhihi
SBR	*Lethrinus xanthochilus**	Yellowlip emperor	Reendhoo thun filolhu

	Grouper (Serranidae)		
GRP	*Aethaloperca rogaa*	Redmouth grouper	Ginimas faana
GRP	*Anyperodon leucogrammicus*	Slender grouper	Boalhajehi faana
GRP	*Cephalopholis argus*	Peacock hind	Mas faana
GRP	*Epinephelus fuscoguttatus*	Marble grouper	Kas faana
GRP	*Plectropomus areolatus*	Squaretail grouper	Olhu faana
GRP	*Plectropomus pessuliferus*	Roving coral grouper	Dhon olhu faana
GRP	*Plectropomus laevis*	Black-saddled coral grouper	Kula olhu faana
GRP	*Variola louti*	Moontail seabass	Kanduhaa
	Tuna (Scombridae and Xiphiidae)		
KAW*	*Euthynnus affinis*	Kawakawa	Latti
WHO*	*Acanthocybium solandri*	Wahoo	Kurumas
DOG*	*Gymnosarda unicolor*	Dogtooth tuna	Voshimas
SL	*Istiophorus platypterus*	Indopacific sailfish	Fangandu hibaru
THL	Cornetfish (Fistularidae)	Cornetfish (species level data absent)	Tholhi
	Barracuda (Sphyraenidae)		
THL	*Sphyreana forsteri*	Bigeye barracuda	Faru tholhi
THL	*Sphyreana barracuda*	Great barracuda	Maa tholhi
	Others		
FIY*	*Coryphaena hippurus*	Dolphinfish	Fiyala
SQR	Holocentridae	Mainly sabre squirrelfish	Raiverimas